Mobile maintenance management systems in healthcare clinics: a cross-sectional study

# Abstract

Recent studies regarding mobile maintenance management systems focus on an organisation’s specific industries, processes, and technologies. However, there is a recognised need for further investigation of mobile maintenance management systems in decentralised organisations with branches across the country. This study is based on data gathered from the Healthcare Clinics organisation’s information system. We examined the effect of implementing real-time mobile maintenance management systems on preventive and corrective service calls. A cross-sectional investigation showed unique preventive and corrective maintenance analysis via eight repair types in healthcare clinics. In addition, gamma analysis showed that after implementing the new system, the duration of maintenance time reduced significantly for all maintenance types. Furthermore, Poisson analysis indicated that the users adopted the new system, as shown by increased service calls. Embracing the new system strongly affects both maintenance time and extent of use, mainly in three categories of repairs: (1) carpentry and frames, (2) electrical, and (3) sanitation. The operational contribution is the feasibility of using a digital maintenance system according to the organisation’s needs and types of maintenance and repairs. Furthermore, the research facilitates practical knowledge for managers in decentralised organisations.

Keywords: Information communication technologies; mobile maintenance management system; maintenance; preventive and corrective maintenance; repair type.

# Introduction

The research aim is to comprehensively explore the impact of information communication technologies (ICT) in healthcare organisations, specifically focusing on mobile maintenance management systems (MMMS). Drawing from the Resource-Based View (RBV) theoretical framework (Barney, 1991), this study examines MMMS as a strategic organisational resource that potentially offers a competitive advantage in service organisations. The RBV emphasises organisational internal resources that are important in establishing and maintaining sustainable competitive advantages (Barney, 1991; Wernerfelt, 1984, 1995). According to Teece et al. (1997) and Barney (2001), RBV underscores the significance of an organisation’s resource configuration as a determinant of unique performance outcomes.

Furthermore, this study examines the improvements in various operational activities by analysing the gap created in corrective and preventive maintenance indicators before and after implementing the MMMS. By conducting a detailed cross-sectional analysis of various maintenance vs. repair types within service organisations and considering the integration of digital systems. The research harnesses real data from the information system to provide in-depth insights. Exploring organisational resource capabilities and improvements harnesses the RBV theory (Barney, 1991) in evaluating the operational implications of MMMS as enabling competitive advantage. Thus, this study significantly contributes to research in healthcare clinics’ ICT and maintenance fields and enriches the empirical understanding through the RBV lens.

The research contributes valuable insights and practical tools for managers, especially in assessing digital systems’ economic viability and operational impact on maintenance. Additionally, an in-depth examination of the findings of using a digital system will improve the ability to decide which combination of maintenance and repair types contributes significantly to improving maintenance efficiency.

Many studies have examined maintenance management systems (Fu et al., 2004; Jain et al., 2016; Labib, 1998; Mendes et al., 2022; Moumen et al., 2022; Wienker et al., 2016). However, MMMS is a new classification that has hardly been explored (Yousefli et al., 2017), and there is limited literature concerning mobile apps (Jantunen et al., 2010; Schoenherr, 2016; Shiau et al., 2019). Our approach, guided by RBV, addresses this gap by investigating MMMS as a real-life technological tool and a strategic asset that substantially enhances organisational capabilities. The paucity of quantitative studies based on data in this domain can be attributed to the challenges associated with mobile app data retrieval and organisational data privacy concerns (Zhang et al., 2016).

Research on MMMS usually focuses on a specific domain (Arnaiz et al., 2006; Costa & Lopes, 2021; Jantunen et al., 2010; Lin et al., 2011; Selvakumaran et al., 2022; Sumaila & Bahsi, 2022).

Employing RBV theory, our study distinctively increases the understanding of MMMS’s role in strengthening the internal capabilities of decentralised service organisations, particularly in the healthcare sector, where such systems are underutilised. This exploration offers a fresh perspective, diverging from previous studies anchored with industrial contexts (Bouabdallaoui et al., 2020; Emmanouilidis et al., 2009).

The study delves into the application of MMMS and addresses unique challenges. Those challenges include diverse maintenance requirements across various locations and coordinating maintenance tasks within an extensive organisational framework. The study focuses on two dependent variables in maintenance — time and service calls — analysing them within eight distinct repair types. The ‘time’ variable covers the maintenance duration, while ‘service calls’ encompass a range of maintenance-related activities.

The term’ time’ encapsulates various durations associated with maintenance activities, including three types of maintenance time: total, corrective, and preventive. Hence, ‘time’ is not merely a measure of duration but is intricately categorised into different aspects of maintenance activities. ‘Service call’ is a formal request initiated by an employee to the maintenance department addressing repair or maintenance. ‘Time’ and ‘Service call’ variables were examined cross-sectionally within eight distinct repair types: air conditioning, building structures, carpentry, frames, electrical, paint works, refrigeration, sanitation, and other miscellaneous facilities. The data collection spans two distinct periods: pre-implementation (January 1, 2017, to September 1, 2019) and post-implementation (September 1, 2019, to December 31, 2021).

The study employed the systems applications and products in data processing (SAP). SAP is an Enterprise Resource Planning (ERP) software that seamlessly integrates data and information across the organisation. By using SAP for data collection, we ensure a robust and systematic approach to the database. In the domain of healthcare, ERP systems are capable of integrating with dedicated systems such as customer relationship management (CRM), supply chain management (SCM), and clinical decision support systems (DSS) (Lee & Kwak, 2011). Integrating maintenance activities enables efficient monitoring of hospitals, facilitating real-time data (Rajagopal, 2002). After collecting the database, we used three statistical models to analyse this data: (1) gamma regressions, (2) Poisson regressions, and (3) t-tests for two independent samples. These statistical approaches were designed to provide a comprehensive understanding of the impact of MMMS implementation on maintenance efficiency and effectiveness.

Therefore, the main research question is: *Does the implementation of an MMMS improve the performance of a maintenance department in eight types of activities in a decentralised organisation?* The uniqueness of the current study is by addressing the facilities’ maintenance activities in two dimensions: (1) corrective and preventive maintenance and (2) in the context of eight types of maintenance activities in a decentralised large healthcare organisation with branches across the country. To the researchers’ knowledge, MMMS has not previously been explored in a decentralised healthcare organisation. This exploration into a decentralised context provides a novel perspective distinct from existing studies, which have primarily focused on more centralised (Backman & Helaakoski, 2011; Bouabdallaoui et al., 2020; Selvakumaran et al., 2022; Stefan Bankosz & Kerins, 2014).

This research offers three main contributions: (1) It adds to research knowledge using maintenance data and an innovative model via cross-sectional analysis. To the authors’ knowledge, little previous research in this field has been based on real data. This cross-sectional analysis approach marks a departure from the methodologies employed in studies such as those that, despite offering informative insights, do not incorporate real data analysis. Furthermore, it differs from the empirical exploration of Bouabdallaoui et al. (2020), which lacks the utilisation of cross-sectional analysis in its methodology. (2) It explores operational knowledge for decentralised organisations in the context of both corrective and preventive maintenance, covering eight repair types. This extensive investigation into various maintenance types represents a distinct contribution not examined in previous studies, particularly within healthcare (Almomani & Alburaiesi, 2020; Bouabdallaoui et al., 2020; Yousefli et al., 2017). (3) It identifies the business value of MMMS in improving service efficiency throughout operations effectiveness and the internal environment. This exploration of business value in a decentralised healthcare environment introduces a novel aspect to the existing body of literature. Previous literature has primarily focused on the development and implementation of maintenance management systems (Backman & Helaakoski, 2011; Gayialis et al., 2022; Lin et al., 2011; Wang et al., 2017) as well as an extensive literature review about maintenance management systems (Emmanouilidis et al., 2009; Moumen et al., 2022; Yousefli et al., 2017).

The following subsections summarise the literature regarding relevant technologies and maintenance activities, provide a general description of the healthcare clinics’ MMMS, and detail the hypotheses development related to reducing maintenance time and increasing the number of service calls. Section 2 details the material and methods used in this study. Section 3 details the study’s findings. Finally, Section 4 provides a summary with a discussion of the key findings and limitations of the study and future implications for research and practice.

# Literature review

Information communication technologies (ICT) facilitate transparency, ubiquitous in real-time via organisational systems integration and mobile devices that enable employees to work outside the office (Ikumapayi et al., 2022; Manyika et al., 2013; Muzafar & Jhanjhi, 2020). ICT enhances operational activities between supply chain partners in maintenance, warehousing, and logistics (Hu et al., 2015). A computerised maintenance management system is one example of the effective use of ICT (Ismail, 2021). In building facilities management, ICT enables maintenance employees to access maintenance management systems, giving them precise information regarding faults and history (Su, 2009). Su (2009) demonstrated an Enterprise Resource Planning (ERP) system that enabled field workers to conduct daily maintenance activities, enabling the transfer of information with minimum paperwork (Giessmann et al., 2012). ICT for maintenance activities is essential since field workers and technicians can receive information in real-time regarding the fault and the inspection schedule, as well as read machine information from a remote location (Ikumapayi et al., 2022; Muzafar & Jhanjhi, 2020).

MMMS is an ICT software that utilises maintenance activities. Several studies explored MMMS. For instance, Lin et al. (2011) developed an MMMS using Radio Frequency Identification (RFID) in a Taiwanese construction lab to improve instrument inspection maintenance. Jantunen et al. (2010) developed MMMS for the shop floor, utilising Personal Digital Assistants (PDA). They identified its contribution to engineers and technicians. Stefan Bankosz and Kerins (2014) identified several technologies that support maintenance activities in industrial sectors. They developed a prototype app to improve maintenance operations in small food industry organisations. Wienker et al. (2016) delve into an in-depth analysis of the challenges in implementing a maintenance system within the organisation. It examines the causes of failure in such implementations and delineates the required activities of implementing a computerised maintenance management system. Sumaila and Bahsi (2022) explored MMMS for the automotive industry implemented in cars for managing maintenance requests. This diversity in application highlights the adaptability of MMMS to different operational contexts, setting a precedent for its potential implementation in healthcare maintenance management.

Maintenance refers to the operational and administrative actions required to keep facilities in the proper condition for efficient work (Pintelon & Van Puyvelde, 2006) with minimum costs (Kelly, 1989; Kumar et al., 2013). Facilities management is an integral part of operations and maintenance activities (Bouabdallaoui et al., 2020). More than 60% of the expenses of physical assets are related to operation and maintenance requests (Garg & Deshmukh, 2006; Liu & Issa, 2016; Madureira et al., 2017). For instance, Garg and Deshmukh (2006) indicated that electricity and maintenance costs account for the most significant share when planning the operational budget.

The high costs of operational and maintenance activities are due to inefficient work practices (Zhan et al., 2018). According to (Yousefli et al., 2017), inefficiency in process and maintenance is even more strongly emphasised in hospitals and clinics. As a result, employees and patients feel discomfort and dissatisfaction (Yousefli et al., 2017).

Maintenance management systems in industrial organisations, hospitals, and clinics hold and manage requests for preventive and corrective maintenance faults (Ahmad & Kamaruddin, 2012; Chen et al., 2017; Gómez-Chaparro et al., 2020; Hamdi et al., 2012; Zaher et al., 2011). Following the RBV, these systems are considered essential organisational resources (Barney, 1991) that improve the efficiency and effectiveness of healthcare services. Corrective maintenance requests refer to unexpected faults or non-scheduled activity in equipment or machines. Faults should be fixed quickly to facilitate continued regular operation (Chen et al., 2017; Sheut & Krajewski, 1994; Vathoopan et al., 2018).

Resolving maintenance requests quickly reduces employee and patient discomfort and dissatisfaction (Bortolini & Forcada, 2020). Examples of maintenance requests include problems with automated doors that will no longer open, broken furniture, and air conditioning and ventilation problems (Bortolini & Forcada, 2020; Gómez-Chaparro et al., 2020). Typically, maintenance requests are opened by the employees who encounter the fault. Preventive maintenance requests refer to scheduled, periodic, or planned maintenance to prevent incidents and disruption by recurrent inspections of equipment and machines while they are in good working condition (Almomani & Alburaiesi, 2020; Kannan, 2020; Zaher et al., 2011).

Maintenance requests are generated daily, and the maintenance team deals with the faults according to their priority in the maintenance management system (Almomani & Alburaiesi, 2020; Becerik-Gerber et al., 2012). The maintenance management system records the maintenance request along with the description, urgency, location, and category of the fault (Bouabdallaoui et al., 2020; Federspiel, 2000; Gunay et al., 2019; Yang et al., 2018), such as electrical, heating, ventilation, or air conditioning (Bortolini & Forcada, 2020; Gómez-Chaparro et al., 2020). A maintenance management system is used for preventive and corrective maintenance, calculating the mean time between faults and downtime, as well as producing reports (Almomani & Alburaiesi, 2020)..

Maintenance optimisation and improvement refer to analysis from mathematical models (de Jonge & Scarf, 2020). An optimal periodic inspection model for failure was based on a hypothetical example using the gamma process (Abdel-Hameed, 1987). van Noortwijk (2009) suggested using the gamma process as a model for optimising maintenance, which has been proven to be useful in determining optimal inspection and maintenance decisions. Optimal maintenance decisions can be made by using the gamma process because of its variety of uses (Kallen & Van Noortwijk, 2005). Another maintenance model for managing the failure behaviour of technical systems, in particular electrical and electronic faults, uses the Poisson process (Hosseini et al., 1999). The Poisson process is a good basis for research that predicts the corrective maintenance of other failure process types (Andrzejczak et al., 2018).

Health clinics primarily focus on providing optimal medical services to the patient population, and all organisational systems assist in achieving this goal. Preventive maintenance services are one of the organisational systems that can improve and optimise the provision of medical services.

# Scattered location problems related to maintenance management systems

Health clinics primarily focus on providing optimal medical services to the patient population, and all organisational systems assist in achieving this goal. Preventive maintenance services are one of the organisational systems that can improve and optimise the provision of medical services. Therefore, maintenance service activities contribute to supporting the clinic’s core business activities (Shohet & Lavy, 2017). Maintenance’s role is to prevent safety risks and ensure smooth operations (Ciarapica et al., 2008). Proper maintenance management leads to financial benefits such as reduced operational and supply chain costs and increased efficiency (Lega et al., 2013).

In a decentralised organisation, effectively managing maintenance operations is complex, mainly due to the dispersed nature of equipment and integration with various suppliers and maintenance tasks. This complexity is prevalent across various sectors, from industrial asset management to healthcare systems (Gayialis et al., 2022). Most maintenance models developed multi-component systems for centralised production systems and maintenance activities located at a close geographical distance. Therefore, such models cannot be applied to geographically scattered sites such as healthcare clinics (Camci, 2015; Nguyen et al., 2018).

Given that the healthcare clinics in Israel are geographically scattered, maintenance activities are managed from the main offices. Therefore, a stable and available information system is required to transfer information between the healthcare clinics and the maintenance offices. ICT is an important element for maintenance in geographically distant organisations. For instance, mobile E-maintenance enables technicians to access necessary information from assets located anywhere and at any time, regardless of their geographic location (Campos et al., 2009). Nowadays, organisations and healthcare clinics can use advanced ICT, such as the Internet of Things (IoT) and Industry 4.0 (Gayialis et al., 2022), to transmit real-time machines and equipment data to technicians 24/7, reducing travel time and cost.

Wang et al. (2017) demonstrate the effectiveness of mobile agent cloud-based preventive maintenance, showcasing how advanced technologies can significantly enhance maintenance management in complex, decentralised organisations, which can be helpful in healthcare clinics and hospitals. They discussed the difference between the client-server and mobile agent computing architectures.

# Healthcare clinic’s maintenance management system

This section demonstrates how healthcare clinics in Israel manage maintenance requests regarding physical assets and service maintenance, focusing on integrating technology and policy frameworks. The clinics’ sophisticated internet infrastructure is more than just a communication tool; it is a fundamental component of the maintenance management system.

The maintenance team is responsible for 458 clinics in five areas, each equipped with state-of-the-art internet facilities and SAP software. This consistent technological infrastructure across all clinics, reinforced by the SAP system, plays a vital role in upholding a uniform standard in maintenance management. The advanced internet connectivity and the SAP software support communication and enable efficient tracking and management of varied maintenance tasks.

By ensuring real-time updating of maintenance requests and efficient dispatch of technicians, the system plays a pivotal role in the overall effectiveness of the maintenance operations. All maintenance requests are categorised as preventive or corrective maintenance. The requests are prioritised from low to immediate activities. This prioritisation can significantly reduce downtime in healthcare facilities. In this context, the diverse range of repair types underscores the necessity for a robust and responsive maintenance management system. The seven most common repair types include building, carpentry and frames, sanitation, electrical, paintwork, air conditioning and ventilation, and refrigeration.

Only employees can open maintenance requests using an iPad with the maintenance management system integrated with the SAP software. This system, strengthened by reliable internet connectivity and SAP’s functionalities, enables comprehensive monitoring and analysis of maintenance patterns, aiding in the ongoing enhancement of maintenance procedures.

The process of opening a maintenance call is as follows: The request is automatically transferred to a call centre that monitors open service calls and passes the request to the maintenance department, which employs ten technicians and a manager with relevant qualifications. The assignment of technicians is carefully strategised, considering the urgency of maintenance requests and geographical factors, maximising efficiency in response times and use of resources.

After a malfunction is fixed, the technicians close the request, and the manager records the service call as resolved. This finalisation step is essential, as it contributes to a database that is instrumental in evaluating maintenance effectiveness and pinpointing potential enhancements. Suppose the technicians identify an additional potential problem. In that case, they open and amend a service call with the iPad. After the problem is resolved, the technician manager terminates the request.

This forward-thinking strategy, supported by a solid technological and policy foundation, demonstrates the clinic’s dedication to upholding superior healthcare services. The process is detailed in Figure 1. The maintenance department’s performance is measured by the average time between opening and terminating requests.

**[[ Place Figure 1 about here ]]**

# Hypothesis development

It is possible to reduce the repair time to a minimum and, thus, reduce the downtime of systems (Sahoo & Liyanage, 2008). Deploying an MMMS reduces repair time by decreasing the time taken to communicate about production problems and by improving the quality of shared information (Mohammadfam et al., 2014). Thus, we propose the following hypothesis:

Hypothesis 1. a: Maintenance time will reduce after implementing the MMMS.

Preventive and corrective maintenance operations require different amounts of time to resolve (Marquez & Heguedas, 2002). Preventative maintenance is based on a schedule and includes regular repairs and periodic replacements that can reduce repair time and downtime (Onoshakpor, 2014). Furthermore, the policy of preventive replacements performed at fixed times makes it possible to implement logistics in decentralised organisations with large populations and geographical dispersion (Bajestani & Banjevic, 2016). Thus, we propose the following hypothesis:

Hypothesis 1. b: The reduction of maintenance time after implementing the MMMS will be different for corrective and preventive maintenance.

Previous studies mainly analysed the effects of MMMS according to maintenance type (Bajestani & Banjevic, 2016; Marquez & Heguedas, 2002) and activity environment (Sidibé et al., 2016). For example, Sidibé et al. (2016) investigated a model that refers to system maintenance time according to its activity environment. To the best of the authors’ knowledge, previous studies have not investigated the impact of MMMS implementation by repair type. Thus, we propose the following hypothesis:

Hypothesis 1. c: The reduction of maintenance time after implementing the MMMS will be different depending on the repair type.

Organisations that create new ways of communicating through apps increase customer engagement (Wang et al., 2015). Furthermore, enterprise applications increase communication and integration between an organisation’s systems (Levi-Bliech et al., 2018). A study conducted in five organisations that started using a mobile application showed improved responses to customer preferences (Pousttchi & Habermann, 2009). Therefore, we propose that implementing the MMMS will increase the end users’ employment when requesting maintenance services. Hence, the next set of hypotheses is proposed.

Hypothesis 2.a: The number of calls per week for maintenance services will increase after implementing the MMMS.

Hypothesis 2.b: The increase in the number of calls per week for maintenance services after implementing the MMMS will differ between corrective and preventive maintenance.

Hypothesis 2.c: The increase in the number of calls per week for maintenance services after implementing the MMMS will differ by repair type.

# Material and methods

## Data collection

Data from 6,997 maintenance records were collected over 167 weeks from the organisational databases included for each maintenance service call. Fields extracted included “Start maintenance service time,” “Finish maintenance service time,” and “Repair type.” Few studies on maintenance have been based on real-world scenarios (de Jonge & Scarf, 2020).

Contrary to traditional survey methods often discussed in SCM research, such as those outlined by Forza (2002), the methodology in this study involved data extraction from the healthcare clinic’s SAP system. Data extraction was chosen for its central role in the organisation’s operations. The SAP system’s robust enterprise resource planning (ERP) capabilities enabled the comprehensive aggregation of operational data and seamless data flow (Gupta & Kohli, 2006; Madapusi & D’Souza, 2012; Nah et al., 2001). This approach was aligned with the study’s objective to explore the practical aspects of maintenance activities in a real-world context. The utilisation of the SAP system, diverging from conventional survey approaches, ensured the extraction of high-integrity and relevant data.

The dataset was based on a period of four years (from January 1, 2017, to December 31, 2021). A total of 2,465 records (35.2%) were collected before the implementation period (from September 1, 2019, to December 30, 2021), and the rest records 4,532 (64.7%) were collected after implementation. The two periods facilitated a detailed analysis of maintenance operations pre- and post-integration of the SAP system. By comparing the data before and after implementation, we provided insights into its influence on organisational efficiency.

## Descriptive statistics

Tables 1 and 2 present the descriptive statistics for maintenance time and service calls, respectively. The Repair Type column describes the various repair types; the Period Time column defines the time before and after the system implementation; the next columns contain data on group sample size and the means and standard deviations of the dependent variables (DVs). The DVs examined in the three comparisons are: (i) total maintenance time and service calls, (ii) corrective maintenance time and service calls; and (iii) preventive maintenance time and service calls.

**[[Place Table 1 about here]]**

**[[Place Table 2 about here]]**

## Data analysis

H1.a and H1.b were tested with the DVs of the maintenance team’s mean resolution time before and after implementation (N = 1,844 in model (1); N = 644 in model (2); N = 1,636 in model (3)). The DVs represent the time it took for the manager to close the maintenance activities manually (before implementation) compared to after the implementation of the MMMS. H2.a and H2.b were tested using the count of maintenance activities per week as the unit of analysis (N = 1,844 in model (4); N = 644 in model (5); N = 1,636 in model (6)). A gamma regression was used in models (1)–(3), and Poisson regression was used in models (4)–(6). The dependent variable before and after implementation was categorised as binary.

Models (1) and (4) refer to total maintenance activities, models (2) and (5) refer to corrective maintenance activities, and models (3) and (6) refer to preventive maintenance activities (Table 3). We tested the gamma and Poisson regressions with before and after system implementation as the principal variable.

**[[Place Table 3 about here]]**

H3.a and H3.b were tested by *t*-test for two independent samples (before and after system implementation). Table 4 presents the results of the *t*-tests for all the DVs. The first column describes the repair types. The next columns show the mean difference between the two DVs in the three comparison groups. Tables 1 and 2 present the mean and SD for each DV.

**[[Place Table 4 about here]]**

Figures 2 and 3 present three panels corresponding to the three comparison groups of maintenance. The plots show the differences in the DVs before and after system implementation for each repair type.

**[[ Place Figure 2 about here ]]**

**[[ Place Figure 3 about here ]]**

# Results

The first part of the results concerning maintenance time shows that the maintenance time is reduced after implementing the MMMS, as shown in Table 3. The total maintenance time was significant and negatively affected after implementing a new system, as shown in model (1), and this finding confirms H1.a hypothesis. These findings are consistent with those presented in the previous literature. Sahoo and Liyanage (2008) highlighted that integrated CMMS helps avoid wasting time and resources. Garcia et al. (2004) found that “online” maintenance enables the maintenance operator to respond in real-time. Campos et al. (2009) found that mobile e-maintenance reduced the time by sending a real-time notification to the maintenance engineer. In addition, we found that the preventive and corrective maintenance time had significant negative effects after implementing a new system, as shown in models (2) and (3), and confirmed the H1.b hypothesis. These findings are aligned with prior studies. Jain et al. (2015) demonstrated that mobile preventive maintenance strategies reduce major breakdowns, setup, and adjustment losses. Aniki and Akinlabi (2013) observed that using Computerized Maintenance Management System software effectively prevents equipment failure before it occurs. They also stated that the software allowed the maintenance department to decrease corrective maintenance time.

Finally, the results regarding Maintenance time presented in Table 4 indicate that hypothesis H1.c is significant for several repair types. The results for the building, carpentry and frames, electrical, other facilities, and sanitation show that maintenance time was reduced after implementing the new system in all three maintenance activities. The effect on air conditioning, paintwork, and refrigeration repairs was insignificant after the MMMS implementation.

The second part of the results related to the volume of service calls for maintenance activities shows that the number of calls increased after implementing the MMMS, as shown in Table 3. The number of weekly calls for all maintenance services has a significant and positive effect after implementing the MMMS, as shown in model (4) and confirms the H2.a hypothesis. The finding collaborates with the former research. Dekleva (1992) discovered that the influence of modern information maintenance systems increases the number of users and their understanding and involvement in the system. Legner et al. (2011) claimed that mobile business applications positively influence use and user satisfaction and that the more significant benefits were in service and maintenance scenarios. Gebauer et al. (2004) presented that mobile business applications directly positively influence user satisfaction and indirectly influence use. Drożyner (2021) found that the impact of the implementation of new management system technologies was in increasing the consumption of the system by the employees. Additionally, we found a significant effect after implementing the MMMS on the number of calls related to preventive maintenance activities opened each week, as shown in model (6) and support H2.b. Furthermore, we did not find a significant effect after implementing the MMMS on the number of calls related to corrective maintenance activities opened each week, as shown in model (5) and did not support H2.b.

This finding stems from the fact that failures or malfunctions occur randomly and are resolved by corrective maintenance (Adhikari & Pal, 2021; Scutariu & Albert, 2006).

Finally, the results concerning the volume of service calls for maintenance activities reveal in Table 4 that hypothesis H2.c is significant. Thus, the number of calls for maintenance services after the implementation increased in three repair types: building, carpentry and frames, and sanitation. No significant evidence was found in air conditioning, other facilities, paintwork, or refrigeration repair types. A unique outcome was found in the building repair type, which showed a reduced number of calls for maintenance services after implementation.

# Discussion

Our research focuses on two critical dependent variables in maintenance: time and service calls. The DVs were analysed with three comparison maintenance groups – total, corrective, and preventive – cross-sectionally against eight repair types. The data were collected by SAP software and tested with three statistical models: gamma and Poisson regressions and a *t*-test for two independent samples.

## Key findings

This research has two key findings. The first refers to improved maintenance times (H1.a, H1.b, and most of H1.c). After implementing the new MMMS, the length of maintenance time reduced significantly for all maintenance types. This improvement aligns with the RBV theory (Barney, 1991; Borchert, 2008), as the efficient use of MMMS as a strategic resource contributes to enhanced operational efficiency, an essential factor for gaining a competitive advantage in healthcare maintenance. The negatively affected repair types related to preventive maintenance activities. Hence, the MMMS improves service efficiency in two organisational environments. First, operational efficiency improves the internal environment. For example, clinical personnel receive accessible and real-time information about their patients without computer malfunctions, and the medicine refrigerators work in an improved and more efficient manner and sustain the integrity of medicines and vaccines. Second, customer service improves the external environment. For example, the patient receives administrative aid and medical treatment at the appointed time without a delay when the information and electrical systems are working correctly. In addition, when air conditioning and plumbing systems function correctly, the patient has a more pleasant stay and experience.

The second key finding refers to the increase in the frequency of maintenance service calls via the new MMMS (H2.a and H2.b). This enhancement, in line with RBV principles, illustrates the strategic importance of MMMS in promoting more efficient use of resources, thus enhancing both internal operations and patient services (Taher, 2012). The positive effect strongly impacted three repair types (1) carpentry and frames, (2) electrical, and (3) sanitation (H2.c). The MMMS is more friendly and accessible than the old process. In addition, the clinics’ employees (end users) have an easy-to-use way to request the maintenance teams in real-time. As a result, handling maintenance activities is carried out more frequently and improves the clinics’ operation (internal environment) and the patient experience (external environment).

## Limitations

Our research has three main limitations that open avenues for future research. The first limitation refers to the empirical data, which is based only on a single organisation from the health sector in Israel. Future empirical research should gather data from different countries and explore a broader range of industries, including fashion, heavy industry, food, and high-tech, extracted from the organisational operation systems to address this limitation. Future research is important for generalising the results facilitating a more extensive exploration of MMMS success implementation and improvements across various industries.

The second limitation refers to the limited period over which the impacts of the system implementation were measured. Future studies should be based on longitudinal studies that will allow for measuring operational performance over a longer period. The third limitation refers to the outcome of the current study. When an organisation implements new ICT, managers should use restraint when redesigning operational processes. These results should be used carefully until more research explores them for various organisations.

Furthermore, Future research can investigate several corrective and preventive maintenance systems, identifying each system’s advantages and disadvantages. Future research may include other indicators related to sustainability, efficiency, flexibility and availability to continue validating the current research results. Future research can address the optimisation problem of allocating technicians in different geographical locations.

## Contribution

The unique model investigated the impacts of implementing MMMS according to the type of maintenance and treatment by cross-comparison analysis. We examined the effects of the system by measuring the gap in maintenance time and the number of service calls per week on three levels: (1) total maintenance, (2) type of maintenance, and (3) repair type.

The paper represents three contributions to research, practice and society. The research contributions encompass maintenance data and the development of innovative model via cross-sectional analysis. To the authors’ knowledge, little previous research in this field has been based on real data. Additionally, the study used cross-sectional analysis, which is uncommon in previous literature regarding maintenance facilities management. This approach allowed researchers in the field to use another model of data analysis, which facilitated the distinction of each maintenance activity vs. repair type. Consequently, we encourage scholars to investigate further the integration of organisational maintenance systems in other industries, particularly in areas with limited empirical exploration within decentralised service organisations.

The practice contributions refer to operational and economic contexts. The first practical contribution is operational. Managers can decide about the feasibility of using a digital maintenance system according to the organisation’s repair needs and types of maintenance. The system implementation enables the improvement of maintenance resources in decentralised organisations, minimises the maintenance department’s staff, and improves operational efficiency. This elevation, viewed through the lens of RBV, demonstrates how effectively managed resources, such as MMMS, can lead to significant operational improvements, thus strengthening the organisation’s competitive advantage.

The second practical contribution is economic. Effectively reducing maintenance time may decrease the human capital of maintenance departments and the waste of operational systems in decentralised organisations. The outcome is reduced overhead costs, enhanced operational performance, and elevated customer satisfaction and retention. Additionally, healthcare clinics that sustain the high-efficiency performance of their operational and maintenance systems improve customer satisfaction. As a result, the organisation retains the existing customers and maintains the competitive advantage.

The society contributions refer to morbidity and environmental sustainability settings. Healthcare clinics that function seamlessly enable the medical team to provide better patient services and reduce morbidity rates. Furthermore, improved preventive maintenance causes a decrease in the wear and tear of equipment and reduces energy consumption. Those efficiencies contribute to environmental sustainability.

## Conclusions

While the previous literature on the maintenance system frequently focuses on theoretical models for systems implementation rather than analysing data extracted from the maintenance operational system. This study used a different approach by investigating empirical organisational data, analysed by a cross-sectional model between corrective and preventive maintenance vs. eight repair types. Overall, we reported an improvement in two operational aspects: reduced maintenance duration and increased end-user consumption. The improvements were found in corrective and preventive maintenance and most repair types. In so doing, we provide evidence of the operational and economic values gained by implementing a MMMS.

# References

Abdel-Hameed, M. (1987). Inspection and maintenance policies of devices subject to deterioration. *Advances in Applied Probability*, *19*(4), 917-931.

Adhikari, S., & Pal, B. (2021). Random machine breakdown and stochastic corrective maintenance period on a production inventory system with safe period. *International Journal of Mathematics in Operational Research*, *18*(3), 404-432.

Ahmad, R., & Kamaruddin, S. (2012). An overview of time-based and condition-based maintenance in industrial application. *Computers & Industrial Engineering*, *63*(1), 135-149.

Almomani, H., & Alburaiesi, M. L. (2020). Using Computerised Maintenance Management System (CMMS) in Healthcare Equipments Maintenance Operations. *Journal of Environmental Treatment Techniques*, *8*(4), 1345-1350.

Andrzejczak, K., Młyńczak, M., & Selech, J. (2018). Poisson-distributed failures in the predicting of the cost of corrective maintenance. *Eksploatacja i Niezawodność*, *20*(4).

Aniki, A. O., & Akinlabi, E. T. (2013). Implementation of CMMS software for a maintenance plan in a manufacturing industry.

Arab, A., Ismail, N., & Lee, L. S. (2013). Maintenance scheduling incorporating dynamics of production system and real-time information from workstations. *Journal of Intelligent Manufacturing*, *24*, 695-705.

Arnaiz, A., Emmanouilidis, C., Iung, B., & Jantunen, E. (2006). Mobile maintenance management. *Journal of International Technology and Information Management*, *15*(4), 2.

Backman, J., & Helaakoski, H. (2011). Mobile technology to support maintenance efficiency—Mobile maintenance in heavy industry. (Ed.),^(Eds.). 2011 9th IEEE International Conference on Industrial Informatics.

Bajestani, M. A., & Banjevic, D. (2016). Calendar-based age replacement policy with dependent renewal cycles. *IIE Transactions*, *48*(11), 1016-1026.

Balaras, C. A., & Argiriou, A. (2002). Infrared thermography for building diagnostics. *Energy and buildings*, *34*(2), 171-183.

Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of management*, *17*(1), 99-120.

Barney, J. B. (2001). Is the resource-based “view” a useful perspective for strategic management research? Yes. *Academy of management review*, *26*(1), 41-56.

Becerik-Gerber, B., Jazizadeh, F., Li, N., & Calis, G. (2012). Application areas and data requirements for BIM-enabled facilities management. *Journal of construction engineering and management*, *138*(3), 431-442.

Borchert, O. (2008). Resource-based theory: Creating and sustaining competitive advantage. Taylor & Francis.

Bortolini, R., & Forcada, N. (2020). Analysis of building maintenance requests using a text mining approach: building services evaluation. *Building Research &amp; Information*, *48*(2), 207-217. <https://doi.org/10.1080/09613218.2019.1609291>

Bouabdallaoui, Y., Lafhaj, Z., Yim, P., Ducoulombier, L., & Bennadji, B. (2020). Natural Language Processing Model for Managing Maintenance Requests in Buildings. *Buildings*, *10*(9), 160. <https://doi.org/10.3390/buildings10090160>

Camci, F. (2015). Maintenance scheduling of geographically distributed assets with prognostics information. *European Journal of Operational Research*, *245*(2), 506-516.

Campos, J., Jantunen, E., & Prakash, O. (2009). A web and mobile device architecture for mobile e-maintenance. *The International Journal of Advanced Manufacturing Technology*, *45*, 71-80.

Chen, Y., Cowling, P., Polack, F., Remde, S., & Mourdjis, P. (2017). Dynamic optimisation of preventative and corrective maintenance schedules for a large scale urban drainage system. *European Journal of Operational Research*, *257*(2), 494-510.

Ciarapica, F. E., Giacchetta, G., & Paciarotti, C. (2008). Facility management in the healthcare sector: analysis of the Italian situation. *Production Planning & Control*, *19*(4), 327-341.

Costa, R., & Lopes, I. (2021). Productivity Improvement in Manufacturing Systems Through TPM, OEE and Collaboration Between Maintenance and Production: A Case Study. (Ed.),^(Eds.). IFIP International Conference on Advances in Production Management Systems.

de Jonge, B., & Scarf, P. A. (2020). A review on maintenance optimisation. *European Journal of Operational Research*, *285*(3), 805-824.

Dekleva, S. M. (1992). The influence of the information systems development approach on maintenance. *MIS quarterly*, 355-372.

Drożyner, P. (2021). The impact of the implementation of management system on the perception of role and tasks of maintenance services and effectiveness of their functioning. *Journal of Quality in Maintenance Engineering*, *27*(2), 430-450.

Emmanouilidis, C., Liyanage, J. P., & Jantunen, E. (2009). Mobile solutions for engineering asset and maintenance management. *Journal of Quality in Maintenance Engineering*, *15*(1), 92-105.

Federspiel, C. C. (2000). Predicting the frequency and cost of hot and cold complaints in buildings. *HVAC&R Research*, *6*(4), 289-305.

Forza, C. (2002). Survey research in operations management: a process‐based perspective. *International Journal of Operations & Production Management*, *22*(2), 152-194.

Fu, C., Ye, L., Liu, Y., Yu, R., Iung, B., Cheng, Y., & Zeng, Y. (2004). Predictive maintenance in intelligent-control-maintenance-management system for hydroelectric generating unit. *IEEE transactions on energy conversion*, *19*(1), 179-186.

Garcia, E., Guyennet, H., Lapayre, J.-C., & Zerhouni, N. (2004). A new industrial cooperative tele-maintenance platform. *Computers & Industrial Engineering*, *46*(4), 851-864.

Garg, A., & Deshmukh, S. (2006). Maintenance management: literature review and directions. *Journal of quality in maintenance engineering*, *12*(3), 205-238.

Gayialis, S. P., Kechagias, E. P., Konstantakopoulos, G. D., & Papadopoulos, G. A. (2022). A Predictive Maintenance System for Reverse Supply Chain Operations. *Logistics*, *6*(1), 4.

Gebauer, J., Shaw, M., & Gribbins, M. (2004). Usage and impact of mobile business applications-An assessment based on the concepts of task/technology fit.

Giessmann, A., Stanoevska-Slabeva, K., & De Visser, B. (2012). Mobile enterprise applications--current state and future directions. (Ed.),^(Eds.). 2012 45th Hawaii International Conference on System Sciences.

Gómez-Chaparro, M., García-Sanz-Calcedo, J., & Aunión-Villa, J. (2020). Maintenance in hospitals with less than 200 beds: efficiency indicators. *Building Research &amp; Information*, *48*(5), 526-537. <https://doi.org/10.1080/09613218.2019.1678007>

Gunay, H. B., Shen, W., & Yang, C. (2019). Text-mining building maintenance work orders for component fault frequency. *Building Research & Information*, *47*(5), 518-533.

Gupta, M., & Kohli, A. (2006). Enterprise resource planning systems and its implications for operations function. *Technovation*, *26*(5-6), 687-696.

Hamdi, N., Oweis, R., Abu Zraiq, H., & Abu Sammour, D. (2012). An intelligent healthcare management system: a new approach in work-order prioritisation for medical equipment maintenance requests. *Journal of medical systems*, *36*(2), 557-567.

Hosseini, M. M., Kerr, R. M., & Randall, R. B. (1999). A hybrid maintenance model with imperfect inspection for a system with deterioration and Poisson failure. *Journal of the Operational Research Society*, *50*(12), 1229-1243.

Hu, Y.-C., Chiu, Y.-J., Hsu, C.-S., & Chang, Y.-Y. (2015). Identifying key factors for introducing GPS-based fleet management systems to the logistics industry. *Mathematical Problems in Engineering*, *2015*.

Ikumapayi, O. M., Kayode, J. F., Afolalu, S. A., Nnochiri, E. S., Olowe, K. O., & Bodunde, O. P. (2022, 5 - 7 April). A study on AI and ICT for Sustainable Manufacturing. (Ed.),^(Eds.). Proceedings of the International Conference on Industrial Engineering and Operations Manageme, Nsukka, Nigeria.

Ismail, Z.-A. (2021). The requirements for maintenance management systems (MMS) at Malaysian polytechnic: a case study. *Journal of Quality in Maintenance Engineering*.

Jain, A., Bhatti, R. S., & Singh, H. (2015). OEE enhancement in SMEs through mobile maintenance: a TPM concept. *International Journal of Quality & Reliability Management*, *32*(5), 503-516.

Jain, A., Singh, H., & Bhatti, R. S. (2016). Implementation of maintenance management in a medium size industry for optimisation of maintenance cost: a case study. *IUP Journal of Operations Management*, *15*(1), 35.

Jantunen, E., Giordamlis, C., Adgar, A., & Emmanouilidis, C. (2010). Mobile devices and services (*E-maintenance* (pp. 227-246). Springer.

Kallen, M.-J., & Van Noortwijk, J. M. (2005). Optimal maintenance decisions under imperfect inspection. *Reliability Engineering & System Safety*, *90*(2-3), 177-185.

Kannan, M. V. (2020). *Improving industrial corrective maintenance by efficient realisation of self-diagnosis in automated production systems reusing their engineering data*, Technische Universität München].

Kelly, A. (1989). Maintenance and its management. (Ed.),^(Eds.).

Koch, C., Hansen, G. K., & Jacobsen, K. (2018). Missed opportunities: Two case studies of digitalisation of FM in hospitals. *Facilities*.

Kumar, U., Galar, D., Parida, A., Stenström, C., & Berges, L. (2013). Maintenance performance metrics: a state‐of‐the‐art review. *Journal of Quality in Maintenance Engineering*.

Labib, A. W. (1998). World‐class maintenance using a computerised maintenance management system. *Journal of Quality in Maintenance Engineering*.

Lee, C. W., & Kwak, N. (2011). Strategic enterprise resource planning in a health-care system using a multicriteria decision-making model. *Journal of medical systems*, *35*, 265-275.

Lega, F., Marsilio, M., & Villa, S. (2013). An evaluation framework for measuring supply chain performance in the public healthcare sector: evidence from the Italian NHS. *Production Planning & Control*, *24*(10-11), 931-947.

Legner, C., Nolte, C., & Urbach, N. (2011). Evaluating mobile business applications in service and maintenance processes: results of a quantitative-empirical study.

Levi-Bliech, M., Naveh, G., Pliskin, N., & Fink, L. (2018). Mobile technology and business process performance: The mediating role of collaborative supply–chain capabilities. *Information Systems Management*, *35*(4), 308-329. [https://doi.org/https://doi.org/10.1080/10580530.2018.1503803](https://doi.org/https%3A//doi.org/10.1080/10580530.2018.1503803)

Lin, Y.-C., Cheung, W.-F., Hsieh, Y.-C., Siao, F.-C., & Su, Y.-C. (2011). Developing RFID-Based Instruments Maintenance Management in Construction Lab (*Designing and Deploying RFID Applications*. IntechOpen.

Liu, R., & Issa, R. R. (2016). Survey: Common knowledge in BIM for facility maintenance. *J. Perform. Constr. Facil*, *30*(3), 04015033.

Madapusi, A., & D’Souza, D. (2012). The influence of ERP system implementation on the operational performance of an organisation. *International journal of information management*, *32*(1), 24-34.

Madureira, S., Flores-Colen, I., de Brito, J., & Pereira, C. (2017). Maintenance planning of facades in current buildings. *Construction and building materials*, *147*, 790-802.

Manyika, J., Chui, M., Bughin, J., Dobbs, R., Bisson, P., & Marrs, A. (2013). *Disruptive technologies: Advances that will transform life, business, and the global economy* (Vol. 180). McKinsey Global Institute San Francisco, CA.

Marquez, A. C., & Heguedas, A. S. (2002). Models for maintenance optimisation: a study for repairable systems and finite time periods. *Reliability Engineering & System Safety*, *75*(3), 367-377.

Mendes, D. S. F. T., Navas, H. V. G., & Charrua-Santos, F. M. B. (2022). Proposal for a maintenance management system based on the lean philosophy and industry 4.0. *Revista Produção e Desenvolvimento*, *8*(1), e587-e587.

Mohammadfam, I., Bahmani, F., & Mahmoudi, S. (2014). Evaluation of the Implementation of a Computerised Maintenance Management System on the Maintenance and Safety KPIs. *International Journal of Occupational Hygiene*, *6*(2), 96-100.

Moumen, Y., Benhadou, M., & Haddout, A. (2022). Impact of e-maintenance and artificial intelligence tools on costs and benefits *Journal of Operations Management, Optimization and Decision Support*, *2*(2), 18-23.

Muzafar, S., & Jhanjhi, N. (2020). Success stories of ICT implementation in Saudi Arabia (*Employing Recent Technologies for Improved Digital Governance* (pp. 151-163). IGI Global.

Nah, F. F. H., Lau, J. L. S., & Kuang, J. (2001). Critical factors for successful implementation of enterprise systems. *Business Process Management Journal*, *7*(3), 285-296.

Nguyen, H. S. H., Do, P., Iung, B., & Vu, H. (2018). Joint maintenance scheduling and routing optimisation for geographically dis-persed production systems. *in Industrial Maintenance and Reliability Manchester, UK 12-15 June, 2018*, 109.

Olasumbo, M., Kanisuru, A. M., Khumbulani, M., & Innocent, R. B. (2019). E-Maintenance Management System for Optimal Functionality of Machines (*E-Systems for the 21st Century: Concept, Developments, and Applications, Volume 2: E-Learning, E-Maintenance, E-Portfolio, E-System, and E-Voting* (pp. 209-252). Apple Academic Press.

Onoshakpor, R. M. (2014). Maintenance precepts for efficient electricity infrastructure in sub-Saharan Africa: The case of the Nigerian electricity network. (Ed.),^(Eds.). 2014 IEEE 6th International Conference on Adaptive Science & Technology (ICAST).

Pintelon, L., & Van Puyvelde, F. (2006). *Maintenance decision making*. Acco.

Pousttchi, K., & Habermann, K. (2009). Exploring the Organisational Effects of mobile business process reengineering. (Ed.),^(Eds.). 2009 Eighth International Conference on Mobile Business.

Rajagopal, P. (2002). An innovation—diffusion view of implementation of enterprise resource planning (ERP) systems and development of a research model. *Information & Management*, *40*(2), 87-114.

Sahoo, T., & Liyanage, J. P. (2008). Computerised maintenance management systems: For effective plant performance. *Chemical Engineering*, *115*(1), 38.

Schoenherr, T. (2016). Mobile devices and applications for supply chain management: Process, contingency, and performance effects. *Transportation Journal*, *55*(4), 333-381.

Scutariu, M., & Albert, H. (2006). Corrective maintenance timetable in restructured distribution environment. *IEEE transactions on power delivery*, *22*(1), 650-657.

Selvakumaran, P., BASIR, M. A., & FUAD, A. F. A. (2022). LIGHTHOUSE MAINTENANCE MANAGEMENT MOBILE APPS SYSTEM. *Universiti Malaysia Terengganu Journal of Undergraduate Research*, *4*(1), 25-38.

Sheut, C., & Krajewski, L. (1994). A decision model for corrective maintenance management. *The International Journal of Production Research*, *32*(6), 1365-1382.

Shiau, W.-L., Yan, C.-M., & Lin, B.-W. (2019). Exploration into the intellectual structure of mobile information systems. *International journal of information management*, *47*, 241-251.

Shohet, I. M., & Lavy, S. (2017). Facility maintenance and management: a health care case study. *International Journal of Strategic Property Management*, *21*(2), 170-182.

Sidibé, I., Khatab, A., Diallo, C., & Adjallah, K. H. (2016). Kernel estimator of maintenance optimisation model for a stochastically degrading system under different operating environments. *Reliability Engineering & System Safety*, *147*, 109-116.

Stefan Bankosz, G., & Kerins, J. (2014). Mobile technology-enhanced asset maintenance in an SME. *Journal of Quality in Maintenance Engineering*, *20*(2), 163-181.

Su, C. J. (2009). Effective mobile assets management system using RFID and ERP technology. (Ed.),^(Eds.). 2009 WRI International Conference on Communications and Mobile Computing.

Sumaila, F., & Bahsi, H. (2022). Digital forensic analysis of mobile automotive maintenance applications. *Forensic Science International: Digital Investigation*, *43*, 301440.

Surveyors, R. I. o. C. (2000). *Building Maintenance: Strategy, Planning and Procurement*. RICS Books.

Taher, M. (2012). Resource-based view theory. *Information Systems Theory: Explaining and Predicting Our Digital Society, Vol. 1*, 151-163.

Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic management journal*, *18*(7), 509-533.

van Noortwijk, J. M. (2009). A survey of the application of gamma processes in maintenance. *Reliability Engineering & System Safety*, *94*(1), 2-21.

Vathoopan, M., Johny, M., Zoitl, A., & Knoll, A. (2018). Modular fault ascription and corrective maintenance using a digital twin. *IFAC-PapersOnLine*, *51*(11), 1041-1046.

Villa, V., Naticchia, B., Bruno, G., Aliev, K., Piantanida, P., & Antonelli, D. (2021). IoT open-source architecture for the maintenance of building facilities. *Applied Sciences*, *11*(12), 5374.

Wang, J., Zhang, L., Duan, L., & Gao, R. X. (2017). A new paradigm of cloud-based predictive maintenance for intelligent manufacturing. *Journal of Intelligent Manufacturing*, *28*, 1125-1137.

Wang, R. J.-H., Malthouse, E. C., & Krishnamurthi, L. (2015). On the go: How mobile shopping affects customer purchase behavior. *Journal of Retailing*, *91*(2), 217-234.

Wernerfelt, B. (1984). A resource‐based view of the firm. *Strategic management journal*, *5*(2), 171-180.

Wernerfelt, B. (1995). The resource‐based view of the firm: Ten years after. *Strategic management journal*, *16*(3), 171-174.

Wienker, M., Henderson, K., & Volkerts, J. (2016). The computerised maintenance management system an essential tool for world class maintenance. *Procedia Engineering*, *138*, 413-420.

Yang, C., Shen, W., Chen, Q., & Gunay, B. (2018). A practical solution for HVAC prognostics: Failure mode and effects analysis in building maintenance. *Journal of Building Engineering*, *15*, 26-32.

Yousefli, Z., Nasiri, F., & Moselhi, O. (2017). Healthcare facilities maintenance management: a literature review. *Journal of Facilities Management*, *15*(4), 352-375.

Zaher, A., Asmar, R., Mannaa, N., Abu-Shanab, R., Deek, S., & Smaaneh, S. (2011). Developing Maintenance Management System in Al-Arabi Specialized Hospital.

Zhan, J., Ge, X. J., Huang, S., Zhao, L., Wong, J. K. W., & He, S. X. (2018). Improvement of the inspection-repair process with building information modelling and image classification. *Facilities*.

Zhang, C., Sun, Z., Heo, G., Di, L., & Lin, L. (2016). Developing a GeoPackage mobile app to support field operations in agriculture. (Ed.),^(Eds.). 2016 Fifth International Conference on Agro-Geoinformatics (Agro-Geoinformatics).

Zhang, Z., Wang, Y., & Wang, K. (2013). Fault diagnosis and prognosis using wavelet packet decomposition, Fourier transform and artificial neural network. *Journal of Intelligent Manufacturing*, *24*, 1213-1227.

# Tables

Table : Descriptive statistics of Maintenance time

|  |  |  |
| --- | --- | --- |
| Repair Type | Period Time(Before and After implementation) | DV: Maintenance time (days) |
| Total Maintenance |  Corrective Maintenance  | Preventive Maintenance |
| Sample size | Mean | SD | Sample size | Mean | SD | Sample size | Mean | SD |
| Aiֹr condition | Before implementation | 3 | 13.44 | 5.68 | 2 | 16.72 | 0.27 | 1 | 6.89 | 0 |
| After implementation | 16 | 9.73 | 7.31 |  |  |  | 16 | 9.73 | 7.31 |
| Building | Before implementation | 290 | 12.50 | 6.14 | 191 | 11.96 | 6.45 | 260 | 12.72 | 6.32 |
| After implementation | 78 | 8.66 | 7.11 | 18 | 4.61 | 5.86 | 67 | 9.45 | 7.27 |
| Carpentry and frames | Before implementation | 188 | 11.80 | 6.35 | 56 | 11.14 | 6.19 | 166 | 12.15 | 6.55 |
| After implementation | 287 | 8.75 | 5.80 | 93 | 9.00 | 6.52 | 285 | 8.76 | 5.82 |
| Electrical facilities | Before implementation | 183 | 12.06 | 6.42 | 61 | 12.50 | 7.30 | 159 | 12.23 | 6.79 |
| After implementation | 280 | 8.98 | 6.36 | 49 | 7.90 | 6.76 | 278 | 9.06 | 6.52 |
| Other facilities | Before implementation | 27 | 13.25 | 8.79 | 13 | 11.87 | 8.82 | 14 | 14.53 | 8.89 |
| After implementation | 51 | 9.41 | 8.26 | 10 | 10.80 | 6.34 | 42 | 9.08 | 8.60 |
| Paint works | Before implementation | 3 | 16.14 | 8.85 | 3 | 16.14 | 8.85 | - | - | - |
| After implementation | 37 | 11.76 | 8.29 | 3 | 9.04 | 4.99 | 34 | 12.00 | 8.53 |
| Refrigeration facilities | Before implementation | 3 | 13.27 | 9.42 | 1 | 2.54 | 0 | 2 | 18.64 | 2.13 |
| After implementation | 10 | 9.09 | 6.30 | 1 | 13.87 | 0 | 9 | 8.56 | 6.44 |
| Sanitation facilities | Before implementation | 119 | 11.29 | 6.78 | 86 | 10.91 | 6.77 | 47 | 12.22 | 7.25 |
| After implementation | 269 | 8.75 | 6.22 | 77 | 7.95 | 5.95 | 256 | 8.89 | 6.49 |
| Total | Before implementation | 816 | 12.11 | 6.46 | 413 | 11.74 | 6.70 | 649 | 12.47 | 6.62 |
| After implementation | 1028 | 8.96 | 6.44 | 251 | 8.24 | 6.38 | 987 | 9.06 | 6.57 |
| Total all | 1844 | 10.35 | 6.63 | 664 | 10.42 | 6.80 | 1636 | 10.41 | 6.79 |

Table : Descriptive statistics of Maintenance calls

|  |  |  |
| --- | --- | --- |
| Repair Type | Period Time(Before and After system implementation) | DV: Maintenance calls (Number calls per week) |
| Total Maintenance | Corrective Maintenance  | Preventive Maintenance  |
| Sample size | Mean | SD | Sample size | Mean | SD | Sample size | Mean | SD |
| Aiֹr condition | Before implementation | 3 | 1.33 | 0.58 | 2 | 1.50 | 0.71 | 1 | 1.00 | 0 |
| After implementation | 16 | 1.06 | 0.25 |  |  |  | 16 | 1.06 | 0.25 |
| Building | Before implementation | 290 | 5.00 | 4.17 | 191 | 2.35 | 2.81 | 260 | 3.85 | 3.55 |
| After implementation | 78 | 1.42 | 0.80 | 18 | 1.00 | 0.00 | 67 | 1.39 | 0.70 |
| Carpentry and frames | Before implementation | 290 | 2.32 | 1.61 | 56 | 1.64 | 1.59 | 166 | 2.07 | 1.37 |
| After implementation | 78 | 7.29 | 4.01 | 93 | 2.17 | 1.56 | 285 | 6.64 | 3.81 |
| Electrical facilities | Before implementation | 183 | 1.98 | 1.09 | 61 | 1.39 | 0.71 | 159 | 1.75 | 0.97 |
| After implementation | 280 | 4.41 | 2.67 | 49 | 1.69 | 1.16 | 278 | 4.14 | 2.58 |
| Other facilities | Before implementation | 27 | 1.07 | 0.27 | 13 | 1.15 | 0.38 | 14 | 1.00 | 0.00 |
| After implementation | 51 | 1.12 | 0.43 | 10 | 1.30 | 0.67 | 42 | 1.05 | 0.22 |
| Paint works | Before implementation | 3 | 1.00 | 0.00 | 3 | 1.00 | 0.00 |  |  |  |
| After implementation | 37 | 1.11 | 0.31 | 3 | 1.00 | 0.00 | 34 | 1.12 | 0.33 |
| Refrigeration facilities | Before implementation | 3 | 1.00 | 0.00 | 1 | 1.00 | 0.00 | 2 | 1.00 | 0.00 |
| After implementation | 10 | 1.00 | 0.00 | 1 | 1.00 | 0.00 | 9 | 1.00 | 0.00 |
| Sanitation facilities | Before implementation | 119 | 1.39 | 0.78 | 86 | 1.30 | 0.72 | 47 | 1.15 | 0.42 |
| After implementation | 269 | 3.60 | 1.99 | 77 | 1.99 | 1.43 | 256 | 3.18 | 1.96 |
| Total | Before implementation | 816 | 3.01 | 3.07 | 413 | 1.84 | 2.10 | 649 | 2.61 | 2.62 |
| After implementation | 1028 | 4.41 | 3.45 | 251 | 1.88 | 1.38 | 987 | 4.11 | 3.26 |
| Total all | 1844 | 3.79 | 3.36 | 664 | 1.86 | 1.86 | 1636 | 3.52 | 3.11 |

Table : Regression results

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|   | H1.a- Total Maintenance | H1.b-Corrective Maintenance 0 | H1.b- Preventive Maintenance 1 | H2.a- Total Maintenance | H2.b- Corrective Maintenance 0 | H2.b- Preventive Maintenance 1 |
| Variable | (1) | (2) | (3) | (4) | (5) | (6) |
| Intercept | 2.494\*\*\*(0.022) | 2.463\*\*\*(0.320) | 2.523\*\*\*(0.025) | 1.101\*\*\*(0.034) | 0.610\*\*\*(0.049) | 0.959\*\*\*(0.039) |
| After Sys | -0.301\*\*\*(0.029) | -0.354\*\*\*(0.052) | -0.319\*\*\*(0.032) | 0.382\*\*\*(0.042) | 0.240(0.080) | 0.454\*\*\*(0.046) |
| Before Sys | 0 | 0 | 0 | 0 | 0 | 0 |
| Unstandardised coefficients are presented, with standard errors |   |   |   |
| N = 1844 in Models (1)-(2), (7)-(8); N = 644 in Models (3)-(4), (9)-(10); N = 1636 in Models (5)-(6), (11)-(12); |
| \* p < 0.05; \*\* p < 0.01; \*\*\* p < 0.001 |   |   |   |   |

Table : Comparison statistics by repair type

|  |  |  |
| --- | --- | --- |
| Repair Type | Mean diff. Maintenance time (days)((After system implementation- Before system implementation | Mean diff. Maintenance calls (Number calls per week)(After system implementation- Before system implementation) |
| Total Maintenance  | Corrective Maintenance | Preventive Maintenance  | Total Maintenance  | Corrective Maintenance | Preventive Maintenance  |
| Aiֹr condition | 3.71- |  | 2.84 | 0.27- |  | 0.63 |
| Building | \*\*\*3.84- | 7.35-\*\*\* | \*\*\*3.27- | \*\*\*3.58- | \*\*\*1.35- | \*\*\*2.46 |
| Carpentry and frames | \*\*\*3.05- | 2.14-\*\* | \*\*\*3.38- | \*\*\*4.97 | \*\*0.53 | \*\*\*4.56 |
| Electrical facilities | \*\*\*3.08- | \*\*\*4.59- | \*\*\*3.18- | \*\*\*2.42 | 0.30 | \*\*\*2.39 |
| Other facilities | \*\*3.84- | 1.08- | \*\*5.46- | 0.04 | 0.15 | 0.05 |
| Paint works | 4.39- | 7.10- |  | 0.11 |  |  |
| Refrigeration facilities | 4.18- | 11.33 | \*\*10.08- |  | 0.00 |  |
| Sanitation facilities | \*\*\*2.54- | \*\*\*2.96- | \*\*\*3.33- | \*\*\*2.20 | \*\*\*0.69 | \*\*\*2.04 |
| Total | \*\*\*3.14- | \*\*\*3.50- | \*\*\*3.40- | \*\*\*1.40 | 0.04 | \*\*\*1.51 |
| \* p < 0.05; \*\* p < 0.01; \*\*\* p < 0.001 |

# Figures

Figure : Detailed process of maintenance request

#

Figure : Mean maintenance time by repair type for each maintenance category

Panel (i)) Total Maintenance (

Panel (ii)) Corrective Maintenance(

Panel (iii)) Preventive Maintenance(

Figure : Number of calls per week by repair type of each maintenance category

Panel (i)) Total Maintenance)

Panel (ii)) Corrective Maintenance)

Panel (iii)) Preventive Maintenance)

